

EXHIBIT A

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF WEST VIRGINIA
AT CHARLESTON

IN RE: ETHICON, INC., PELVIC REPAIR SYSTEM PRODUCTS LIABILITY LITIGATION	Master File No. 2:12-MD-02327
THIS DOCUMENT RELATES TO WAVE 5 CASES	JOSEPH R. GOODWIN U.S. DISTRICT JUDGE

EXPERT REPORT OF SCOTT GUELCHER, PH.D.

The opinions which are held and expressed to a reasonable degree of scientific certainty are as follows:

I. QUALIFICATIONS

Scott Guelcher, Ph.D.

I received my Bachelor's Degree in Chemical Engineering from Virginia Tech in 1992, my Master's Degree in Chemical Engineering from the University of Pittsburgh in 1996, and my Ph.D. in Chemical Engineering from Carnegie Mellon University in 1999. I completed my training as a Post-Doctoral Research Associate in Biomedical Engineering at Carnegie Mellon University in 2005.

I am currently a Professor of Chemical and Biomolecular Engineering at Vanderbilt University. Prior to my current appointment, I was an Associate Professor from 2012 through 2016 and an Assistant Professor from 2005 through 2012. I was recently appointed a Chancellor's Faculty Fellow for the period 2015 – 2017, and in December 2016 I was appointed the Director of the Vanderbilt Center for Bone Biology in the Department of Medicine at Vanderbilt University Medical Center. In 2016, I taught Design Projects (Spring) and Applied Chemical Kinetics (Fall). In 2017, I am teaching Design Projects (Spring).

My professional experience includes: Associate Scientist and Senior Associate Scientist at Bayer Corporation, Polyurethanes Division, in South Charleston, West Virginia from 1999-2003; Trainee at Philips Research, in Eindhoven, The Netherlands in 1998; Limited Service Employee at Eastman Chemical Co. from 1995-1997; and Chemical Engineer at Eastman Chemical Co. from 1992-1994. I am active in several professional societies, including the American Institute of Chemical Engineers, the American Chemical

Society, the Society for Biomaterials, the Cancer and Bone Society, and the Interdisciplinary Research Society for Bone and Joint Injectable Biomaterials. My research interests include biomaterials design and development, drug and gene delivery, tissue engineering, and *in vitro* models for cancer metastasis to bone.

My experience, education and training and a complete list of my published articles are summarized in my Curriculum Vitae attached to this report as Exhibit A. I have published 83 peer-reviewed articles, including four on the design of scaffolds that degrade in response to secretion of reactive oxygen species and two on oxidation and degradation of polypropylene pelvic mesh. I also have experience in the design of biologic and tissue-engineered grafts for regeneration of cutaneous tissue and bone, having published 24 peer-reviewed papers on biologic tissue grafts. I have co-authored 9 book chapters, given 53 invited presentations, and co-authored 184 abstracts presented at scientific meetings, two of which relate to oxidation of polypropylene in biomedical devices. I am a co-inventor on 11 issued U.S. and European Patents and 20 pending applications.

II. SUMMARY OF OPINIONS

This report is an examination and assessment of the polypropylene mesh utilized in devices manufactured by Ethicon to treat Stress Urinary Incontinence (SUI) and pelvic organ prolapse (POP). All of the opinions presented herein are made to a reasonable degree of scientific certainty and within my field of expertise.

- 1) Polypropylene reacts with molecular oxygen by autoxidation outside the body at elevated temperatures, resulting in chain scission and deterioration in its mechanical properties;
- 2) After implantation in the body, polypropylene reacts with reactive oxygen species secreted by inflammatory cells, resulting in oxidation, chain scission and mesh embrittlement;
- 3) The dynamic environment where the polypropylene mesh is implanted coupled with the foreign body reaction leads to oxidation, chain scission, reduction in molecular weight, embrittlement, degradation, flaking, pitting, and cracking;
- 4) The human body does not stop responding to an implanted mesh, or any frayed particles of mesh released during implantation, unless the product is removed in its entirety;
- 5) The mesh devices examined for this report are intended to last for the lifetime of the patient, but the presence of antioxidants does not permanently protect the PP against degradation, and thus it is not possible to guarantee that it will perform its intended function after implantation;
- 6) The effects of oxidation on the stability of Prolene were known to Ethicon prior to launching its SUI and POP devices, but the company did not consider the risks associated with polypropylene oxidation on the stability of Prolene mesh, to the detriment of patients implanted with the devices;
- 7) Polypropylene mesh is not inert and its properties change after implantation, which can lead to adverse events in an implantee; the use of heavy-weight meshes directly correlates with more exposure of polypropylene to the Foreign Body Reaction and greater changes after implantation, which increases the risk of complications.
- 8) Using autologous fascia lata, allograft, sutures (including polypropylene sutures), or polyvinylidene fluoride (PVDF) mesh does not present with the same chronic complications associated with the material properties of Ethicon's PP mesh. All of these alternative materials, including using a less dense version of its PP mesh, were available when Ethicon's SUI and POP meshes were first commercialized.

III. BACKGROUND

Ethicon sells permanently implantable polypropylene-based meshes intended to treat Stress Urinary Incontinence (SUI) and Pelvic Organ Prolapse (POP). All of the products in this litigation use the same Prolene resin to make the polypropylene-based meshes examined in this report.¹ Prolene was developed by Ethicon in the late 1960s for use as a suture material² and is more than 97% polypropylene. Additives are blended with polypropylene to modify its properties, including the antioxidants dilaurelthiodipropionate (DLTDP) and Santonox-R to protect Prolene during high-temperature processing and long-term storage³, and the blue pigment copper phthalocyanate (CPC) to enhance its visibility.⁴ Prolene resin is manufactured as pellets, which are extruded into monofilaments that are subsequently knit into a specific mesh pattern.⁵

Ethicon's SUI devices consist of their instructions for use (IFU), insertion tools, and a high-density mesh (105 g/m²) knit from Prolene monofilaments that are 6 mil (0.006 inches) in diameter.⁶ The Prosima, Prolift, and Gynemesh POP devices all consist of their IFU, insertion tools, and a lower density mesh (45 g/m², known as Gynemesh⁷) knit from Prolene monofilaments that are 3.5 mil (0.0035 inches) in diameter.⁸ The mesh used in the Prolift+M POP device is a hybrid material comprising a blend of absorbable Monocryl (poly(glycolide-co-ε-caprolactone)) and Prolene. After the Monocryl is absorbed, the density of the remaining Prolene mesh is 28 g/m².⁹

¹ ETH.MESH.04941016; ETH.MESH.01310578; ETH.MESH.03987419; ETH.MESH.07876572; ETH.MESH.00019863; ETH.MESH.0181699

² ETH.MESH.02268619

³ ETH.MESH.02268619

⁴ *Id.*

⁵ ETH.MESH. 03987419; ETH.MESH.01310578

⁶ ETH.MESH.04941016

⁷ ETH.MESH.01310578

⁸ ETH.MESH.00074499

⁹ *Id.*

IV. DISCUSSION

1) Polypropylene reacts with molecular oxygen outside the body by the process of autoxidation

Polypropylene (PP) is a plastic that is formed by a chemical reaction that joins the monomer propylene (which is composed of three carbon atoms and six hydrogen atoms) into a long repeating chain in a process called polymerization.¹⁰ All forms of PP are susceptible to oxidation at the tertiary hydrogen-carbon bond.¹¹

Oxidative attack at the tertiary hydrogen bond is the rate-controlling step in degradation process and results in the PP molecular chain being broken, a process known as chain scission, with the consequent loss in molecular weight. The mechanism of PP autoxidation is shown in Figure 1.¹² The process is autocatalytic, resulting in generation of more PP radicals (PP•) as the reaction progress. Thus, the reaction continues until no more PP can be broken down. The mechanism of PP autoxidation has been investigated extensively since the 1960s and was well known at the time that Ethicon was designing the mesh used in SUI and POP products. As shown in Figure 1, the products of autoxidation include shorter PP chains with carbonyl (C=O) and hydroperoxide (COOH) groups covalently bound to the PP. The presence of these groups can be detected by surface techniques such as FTIR and x-ray photoelectron spectroscopy (XPS) as evidence of

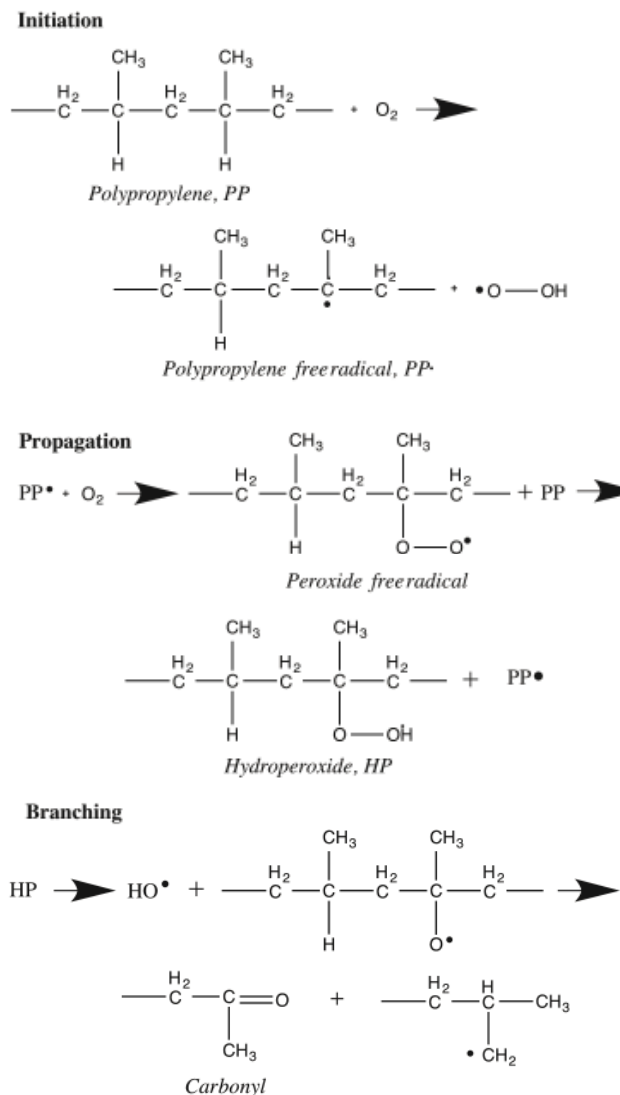


Figure 1. Mechanism of PP autoxidation. Initiation, propagation, and branching reactions lead to chain scission (loss of molecular weight). Products from autoxidation include hydroperoxide and carbonyl groups, which can be detected by analytical methods such as FTIR.

¹⁰ EA Campo. Industrial Polymers. Hanser 2008, p. 74.

¹¹ HH Kausch. The effect of Degradation and Stabilization on the Mechanical Properties of Polymers Using Polypropylene Blends as the Main Example. *Macromol. Symp.* 225:165-178, 2005.

¹² Reference for Figure 1: C Maier, T Calafut. Polypropylene: The Definitive User's Guide and Databook. Norwich, NY: Plastics Design Library, 1998.

oxidation.¹³

As shown in Figure 2, heat and UV radiation accelerate oxidation of PP.¹⁴ Absorption of oxygen is diffusion-controlled, and the amorphous regions of the semi-crystalline PP are the most accessible to diffusion of O₂. The amorphous phase of PP comprises non-crystallizable segments of the PP chains as well as tie molecules that connect two neighboring crystalline domains. Since the toughness of PP depends on the number of tie molecules, cutting of the tie molecules during autoxidation is the primary factor contributing to embrittlement. The key features of oxidation of PP, in terms of the amount of molecular weight loss that is critical for embrittlement to occur are summarized in Figure 3.¹⁵ An important finding from this study is that embrittlement occurs much earlier (~150 hours) than the induction time (~250 hours) determined by the concentration of carbonyl groups and hydroxyl groups associated with the hydroperoxide (COOH) under these conditions. Thus, the induction time overestimates the useful life of PP with respect to its mechanical properties.

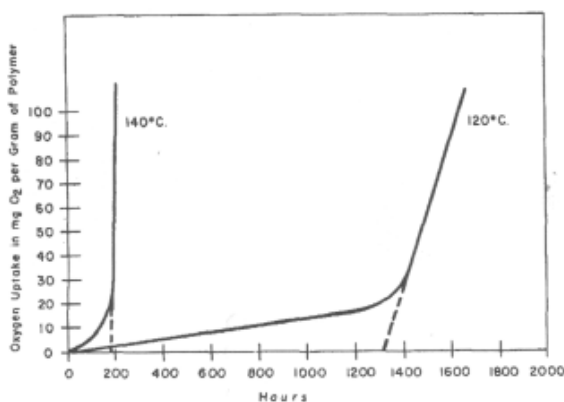


Figure 2. Autoxidation of PP is accelerated at elevated temperatures. Oxygen absorption of stabilized PP increases with time and temperature in 100% O₂. The induction time is determined by extrapolating the autocatalytic constant rate portion of the curve (steeper slope) to the x-axis (dashed line). Reproduced from Oswald and Turi 1965.

The storage stability of unstabilized PP at ambient conditions has also been studied (Figure 4). When PP films were stored at room temperature and atmospheric O₂ concentration, the molecular weight (as measured by intrinsic viscosity) of PP dramatically decreased at 500 days (1.4 years).¹⁶ Thus, while oxidation is accelerated at elevated temperatures and oxygen concentrations (Figure 2), even at ambient temperature and atmospheric oxygen concentration there is chain scission and molecular weight loss.

2) After implantation in the body, polypropylene reacts with reactive oxygen species secreted by inflammatory cells, resulting in oxidation, chain scission and mesh embrittlement;

Liebert et al.¹⁷ (1976) reported the oxidation of unstabilized PP filaments in vivo in a subcutaneous implantation model in hamsters. An induction time of 108 days was determined based on FTIR measurements of hydroxyl (which includes the hydroperoxide

¹³ B Fayolle, L Audouin, J Verdu. Oxidation-induced embrittlement in polypropylene – a tensile testing study. *Polym Degrad Stability* 70:333-40, 2000.

¹⁴ HJ Oswald, E. Turi. The Deterioration of Polypropylene by Oxidative Degradation. *Polymer Engineering and Science*, 1965.

¹⁵ B Fayolle, L Audouin, J Verdu. Oxidation-induced embrittlement in polypropylene – a tensile testing study. *Polym Degrad Stability* 70:333-40, 2000.

¹⁶ HJ Oswald and E. Turi. The Deterioration of Polypropylene by Oxidative Degradation. *Polymer Engineering and Science*, 1965.

¹⁷ TC Liebert, RP Chartoff, SL Cosgrove, RS McCuskey. Subcutaneous implants of polypropylene filaments. *Journal Biomedical Materials Research* 10:939-51, 1976.

COOH) and carbonyl groups. FTIR measurements of hydroxyl and carbonyl groups showed behavior similar to that observed by Fayolle (Figure 3), consistent with the oxidation mechanism. However, Liebert estimated that the induction time for oxidation under *in vivo* conditions (37°C in 3.3% O₂) is approximately 20 years, which is dramatically higher than the measured value of 108 days. The authors suggested that enzymes or other chemicals secreted by cells accelerate the oxidation reaction. Recent papers have shown that this shorter induction time can be explained by the secretion of reactive oxygen species (ROS) by inflammatory cells near the PP fibers that oxidize and degrade the PP fibers *in vivo*.

Upon implantation, the body recognizes PP mesh as a foreign body, which elicits an inflammatory response known as the foreign body reaction.¹⁸ In the early stages, mononuclear cells migrate to the surface of the PP fibers, where they can adhere and participate in the events of the foreign body reaction (Figure 5). Adherent macrophages on the surface of the implanted biomaterial fuse to form foreign body giant cells (FBGCs). Adhesion of macrophages and FBGCs at the biomaterial surface results in an isolated microenvironment between the surface of the biomaterial and the plasma membrane of the cell.¹⁹ In a process known as frustrated phagocytosis, macrophages and FBGCs secrete reactive oxygen species (ROS), acids, and enzymes into this microenvironment. Consequently, the surface of the biomaterial is exposed to high concentrations of ROS, and the chemical composition of the biomaterial will determine its susceptibility to oxidative degradation. As an example, the polyether soft segment of poly(ether urethane)s is known to undergo oxidative degradation. The morphological progression of the foreign body reaction on a poly(ether urethane) surface is shown in Figure 6.²⁰

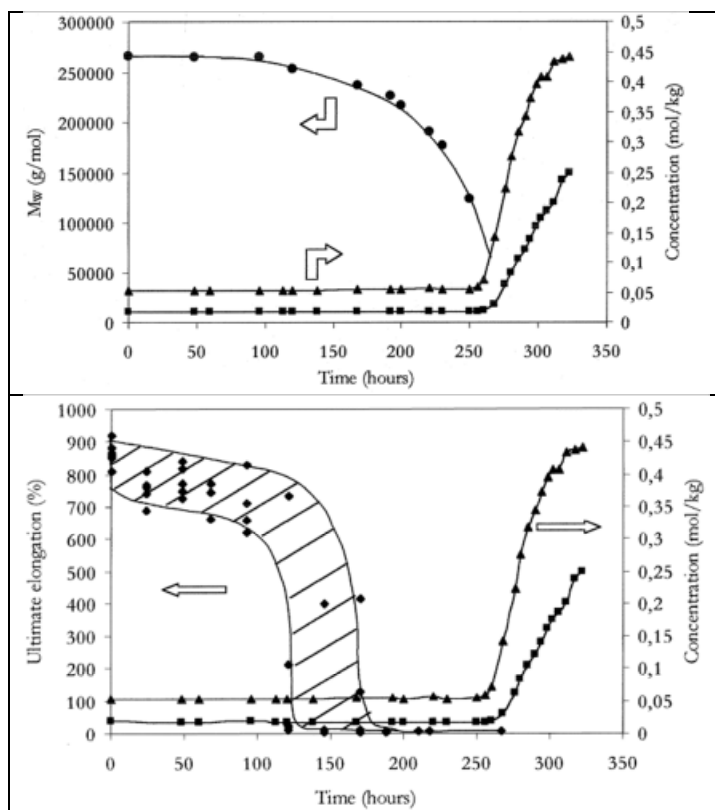


Figure 3. Degradation of unstabilized PP. (A) Molecular weight decreases with time when exposed to oxygen at elevated temperatures (Fayolle et al. 2000). On the right y-axis, the concentration of hydroxyl (triangles) and carbonyl (squares) groups are shown. (B) Evolution of ultimate elongation (diamonds) and hydroxyl (triangles) and carbonyl (squares) groups during exposure to oxygen at elevated temperatures (Fayolle et al. 2000).

¹⁸ JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol.* 20(2): 86–100, 2008.

¹⁹ *Id.*

²⁰ *Id.*

While initial studies identifying adherent macrophages and FBGCs as sources of ROS focused on poly(ether urethane)s, these cell populations have also been reported to infiltrate PP mesh.²¹ In a recent study characterizing the foreign body reaction of PP implants in a rat abdominal wall model, macrophages and foreign body giant cells were observed both in the tissue surrounding the implant and also the implant itself.²²

Thus, within one week after implantation PP mesh was colonized by macrophages and FBGCs. Furthermore, PP mesh samples showed more inflammatory cells than PP sutures. The hernia literature also provides evidence that the foreign body reaction alters PP *in vivo*. In a study evaluating non-degradable meshes explanted from 17 patients that had surgery for repair of abdominal wall defects, a foreign body reaction characterized by granulation tissue and inflammatory cells 3 – 24 months post-implantation was seen.²³ The authors

observed that inflammation near synthetic materials implanted in the abdominal wall persists for years. They further noted that this persistent foreign body reaction can lead to long-term complications, and that further studies are required to evaluate the long-term response of the host tissue to the implanted synthetic graft. Costello et al. also examined explanted PP hernia mesh and noted that the observed degradation of PP fibers was consistent with the oxidation of PP mediated by phagocytic cells during the foreign body reaction.²⁴

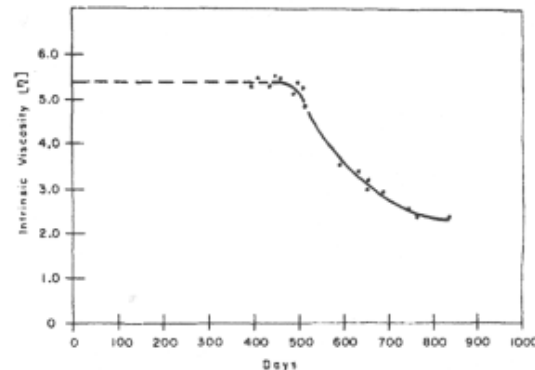


Figure 4. Stability of unstabilized PP at room temperature. Significant molecular weight loss occurs at 500 days. Reproduced from Oswald and Turi 1965.

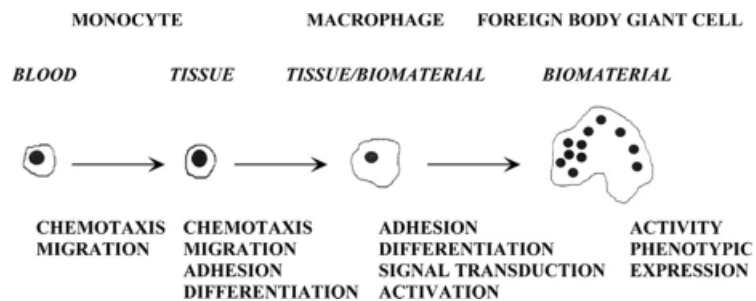


Figure 5. *In vivo* transition from blood-borne monocyte to biomaterial adherent monocyte/macrophage to foreign body giant cell at the tissue/biomaterial interface. There is ongoing research to elucidate the biological mechanisms that are considered to play important roles in the transition to foreign body giant cell development. From Anderson et al. Seminars in Immunology 2008.

²¹ C Mary, Y Marois, MW King, G Laroche, Y Douville, L Martin, R Guidoin. Comparison of the In Vivo Behaviour of Polyvinylidene Fluoride and polypropylene Sutures Used in Vascular Surgery. *ASAIO Journal* 44:199-206, 1998; VV Iakovlev, ET Carey, J Steege. Pathology of Explanted Transvaginal Meshes. *Int. J. Medical, Health, Pharmaceutical and Biomedical Eng.* 8(9):510-513, 2014

²² ML Konstantinovic, E Pille, M Malinowska, E Verbeken, D De Ridder, J Deprest. Tensile strength and host response towards different polypropylene implant materials used for augmentation of fascial repair in a rat model. *Int Urogynecol J* 18:619-26, 2007.

²³ U Klinge, B Klosterhalfen, M. Müller, V Schumpelick. Foreign Body Reaction to Meshes Used for the Repair of Abdominal Wall Hernias. *Eur J Surg* 165: 665–673, 1999.

²⁴ CR Costello, SL Bachman, BJ Ramshaw, SA Grant. Materials Characterization of Explanted Polypropylene Hernia Meshes. *J. Biomed. Mater Res. Part B Appl. Biomater* 83:44-49, 2007; CR Costello, SL Bachman, SA Grant, DS Cleveland, TS Loy, BJ Ramshaw. Characterization of Heavyweight and Lightweight Polypropylene Prosthetic Mesh Explants from a Single Patient. *Surg. Innov.* 14:168-76, 2007.

Three key studies published in 2015 that characterize the host inflammatory response to implanted PP provide further evidence that PP mesh undergoes oxidative degradation *in vivo*. Gynemesh PS and UltraPro, which are Prolene meshes used in Ethicon's POP products, were implanted in rhesus macaques by sacrocolpopexy after an abdominal hysterectomy.²⁵ After 12 weeks

implantation time, the vagina-mesh tissue complexes were harvested and processed for histological and immunohistochemical analysis. Explanted Gynemesh PS and UltraPro meshes showed evidence of a foreign body reaction characterized by a dense mononuclear cell infiltrate near the surface of the mesh fibers. Mononuclear cells staining positive for the pan-macrophage marker CD68 were the cell type present at the highest density adjacent to the mesh fibers. The inflammatory response to all implanted PP meshes was characterized primarily by activated, pro-inflammatory M1 macrophages (an example of macrophages on Elasthane 80A are shown in Figure 7, Top Left).²⁶ The ratio of regenerative M2 macrophages to M1 macrophages was higher for the lower density UltraPro mesh compared to the

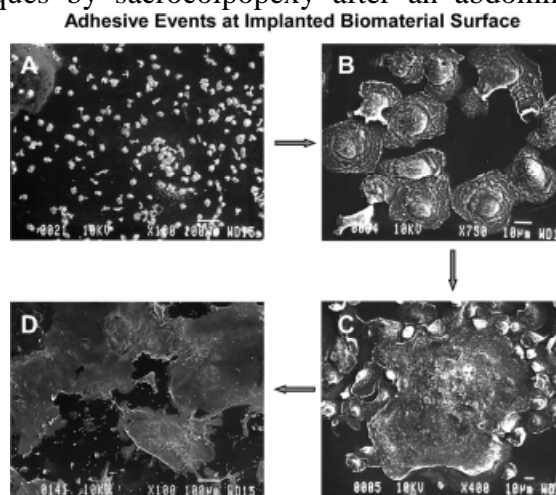


Figure 6. Scanning electron microscopy images of an Elasthane 80A Polyurethane surface from an *in vivo* cage study showing the morphological progression of the foreign body reaction. The sequence of events at the Polyurethane surface includes (A) monocyte adhesion (0 days), (B) monocyte-to-macrophage development (3 days), (C) ongoing macrophage-macrophage fusion (7 days), and (D) foreign body giant cells (14 days). From JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol.* 20(2): 86–100, 2008.

²⁵ BN Brown, D Mani, AL Nolfi, R Liang, S Abramowitch, PA Moalli. Characterization of the host inflammatory response following implantation of prolapse mesh in rhesus macaque. *Am J Obstet Gynecol.* 213(5):668.e1-668.e10, 2015.

²⁶ JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol.* 20(2): 86–100, 2008.

higher density Gynemesh PS. This finding is consistent with the mesh burden concept that the magnitude of the foreign body reaction increases with the amount of mesh in contact with host tissue. Thus, the work by Moalli et al. establishes that the foreign body reaction to implanted PP mesh is dominated by pro-inflammatory M1 macrophages. In a study I co-authored with Dr. Vladimir Iakovlev in 2015, we examined 164 explanted PP pelvic meshes by microscopy.²⁷ Examination of histological sections revealed the presence of inflammatory cells near the surface of PP fibers, and staining for the oxidative enzyme myeloperoxidase expressed by adherent inflammatory cells was positive on the surface of the

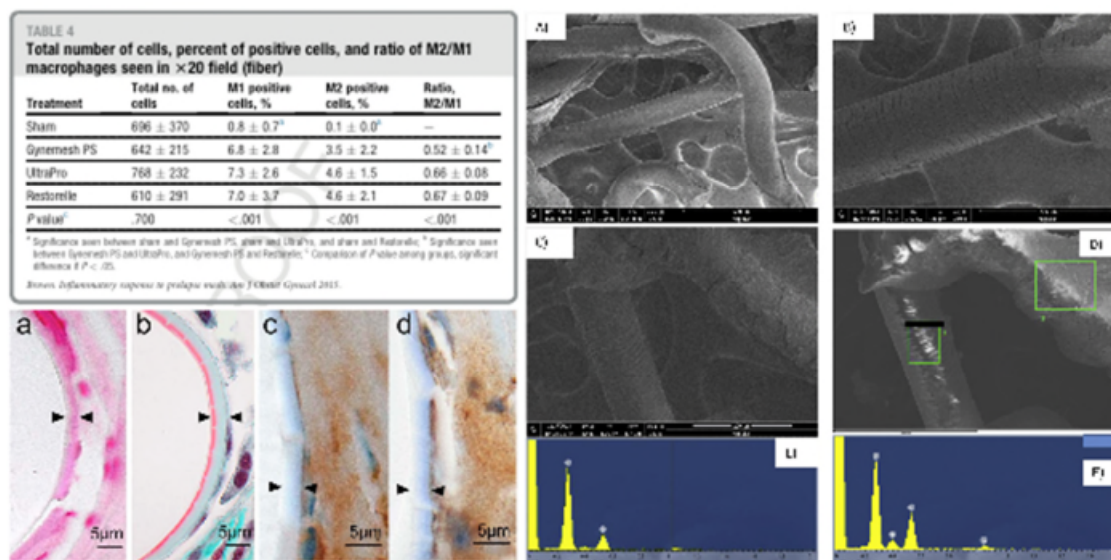


Figure 7. Oxidative degradation of PP mesh *in vivo*. Top Left: Table listing the total number of cells, percent of positive cells, and ratio of M2/M1 macrophages seen in $\times 20$ field (fiber) (Moalli et al., Characterization of the host inflammatory response following implantation of prolapse mesh in rhesus macaque.) Bottom Left: Additional stains of PP mesh, all images taken with 100x oil immersion objective and cropped to a different magnification, polypropylene degradation layer is pointed between arrowheads: (a) Von Kossa stain is negative for calcium in the brittle “bark” (would stain calcium black), (b) trichrome stain shows that the deeper parts of the “bark” have smaller staining porosity (red) than those close to the surface (green) which correlates with TEM findings [Figure 6(b)], (c) immunohistochemical stain for immunoglobulin G (IgG, stained brown). IgG is present in almost all human tissues and fluids. It is deposited on the surface of degraded polypropylene but is not mixed within it. (d) Immunostain for the oxidizing enzyme of inflammatory cells myeloperoxidase (stains brown). (VV Iakovlev. *In vivo* degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients.) Right: A) SEM of explanted Pinnacle Mesh fibers [XP-7]. B) SEM of explanted Pinnacle Mesh fibers [XP-7]. C) SEM of explanted Pinnacle Mesh fibers [XP-7]. D) SEM image with regions selected for EDS. E) EDS Spectra from region 1 in D. F) EDS Spectra from region 2 in D. (A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. *In vivo* oxidative degradation of polypropylene pelvic mesh, *Biomaterials*, 2015.).

degraded layer of the PP fibers (Figure 7, Bottom Left). Another study published in 2015 confirmed that the foreign body reaction to implanted PP mesh results in oxidative degradation of the mesh.²⁸ PP pelvic meshes explanted from 11 patients were characterized by FTIR, GPC, SEM with energy-dispersive x-ray spectroscopy (EDS), TEM, and TGA and compared to meshes that had not been implanted. FTIR spectra of explanted PP mesh showed broad peaks centered at 3400 cm^{-1} , which correspond to hydroxyl and peroxide groups, and at $1700 - 1750\text{ cm}^{-1}$, which correspond to carbonyl

²⁷ VV Iakovlev, SA Guelcher, R Bendavid. *In vivo* degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Appl Biomed Mater Res B: Appl Biomater* 105(2):237-248, 2017.

²⁸ A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. *In vivo* oxidative degradation of polypropylene pelvic mesh. *Biomaterials* 73:131-141, 2015.

groups associated with ketones, aldehydes, and carboxylic acids. Importantly, this study demonstrated that oxidized PP, which does not contain nitrogen, and biological material, which does contain nitrogen, could be distinguished by a combination of EDS and SEM. Regions of PP fibers with transverse cracks that were free of biological material were found to contain oxidized PP (Figure 7 Right). Furthermore, clean PP fibers that showed no evidence of transverse cracking revealed evidence of PP oxidation.

Two recent studies by the Moalli group at the University of Pittsburgh have reported the effects of PP mesh on host tissue and the inflammatory response. When PP mesh was implanted in the vaginal wall of rhesus macaques, mesh stiffness and density were negatively correlated with muscle outcomes, including myofiber function, contraction, and innervation.²⁹ Moalli et al. also examined the inflammatory response in fifteen SUI and twelve POP meshes explanted from 27 women, including two TVT meshes.³⁰ Histological analysis revealed evidence of macrophages, which were predominantly of the M1 pro-inflammatory phenotype, surrounding PP mesh fibers. Matrix metalloproteinase-9 (MMP-9) and MMP-2, which are associated with chronic inflammation, were significantly upregulated in mesh-vagina explants compared to vaginal tissue without mesh.³¹ Mesh explants that were removed due to exposure exhibited significantly higher pro-MMP-9 than those removed due to pain. These findings show that mesh exposure correlates with expression of factors associated with inflammation.

In a manuscript recently accepted for publication, I have shown that PP mesh oxidizes and degrades *in vitro*.³² TVT, Advantage (Boston Scientific), and Lynx (Boston Scientific) mesh specimens were incubated in oxidative medium that mimics the reactive oxygen species (ROS) secreted by adherent inflammatory cells.³³ PP oxidized and degraded *in vitro* in the absence of proteins, as evidenced by the appearance of oxygen (measured by FTIR) and pitting, peeling, and flaking on the surface (measured by SEM). In a patient explant, manual dissection of mesh not fixed in formalin successfully removed protein

²⁹ Z Jallah, R Liang, A Feola, W Barone, S Palcsey, SD Abramowitch, N Yoshimura, and P Moalli. The impact of prolapse mesh on vaginal smooth muscle structure and function. *BJOG* 23:1076–1085, 2016.

³⁰ AL Nolfi, BN Brown, R Liang, SL Palcsey, MJ Bonidie, SD Abramowitch, PA Moalli. Host response to synthetic mesh in women with mesh complications. *Am J Obstet Gynecol* 215:206.e1-8, 2016.

³¹ *Id.*

³² AD Talley, BR Rogers, V Iakovlev, RF Dunn, and SA Guelcher. Oxidation and degradation of polypropylene transvaginal mesh. *Journal of Biomaterials Science: Polym Ed* 28(5):444-458, 2017.

³³ QH Zhao, AK McNally, KR Rubin, M Renier, Y Wu, V Rose-Caprara, JM Anderson, A Hiltner, P Urbanski, K Stokes. Human plasma macroglobulin promotes in vitro oxidative stress cracking of Pellethane 2363-80A: In vivo and in vitro correlations. *J Biomed Mater Res* 27: 379-389, 1993. AE Hafeman, KJ Zienkiewicz, AL Zachman, HJ Sung, LB Nanney, JM Davidson, SA Guelcher. Characterization of degradation mechanisms of biodegradable lysine-derived aliphatic polyurethanes. *Biomaterials* 32(2):419-29, 2011. JL Martin, MK Gupta, JM Page, F Yu, JM Davidson, SA Guelcher, CL Duvall. Synthesis of a Porous, Biocompatible Tissue Engineering Scaffold Selectively Degraded by Cell-Generated Reactive Oxygen Species. *Biomaterials* 35(12):3766-76, 2014. MAP McEnery, S Lu, MK Gupta, KJ Zienkiewicz, JC Wenke, K Kalpakci, D Shimko, CL Duvall, SA Guelcher. Resorbable Poly(thioketal urethane)/Ceramic Composite Bone Cements with Bone-Like Strength. *RSC Advances* 6:109414 - 109424, 2016. JR Martin, CE Nelson, MK Gupta, F Yu, KM Hocking, JM Davidson, SA Guelcher, CL Duvall. Local delivery of PHD2 siRNA from ROS-degradable scaffolds to promote diabetic wound healing. *Adv Healthc Mater* 5(21):2751-2757, 2016.

from the surface, revealing an underlying layer of oxidized PP. XPS analysis of these mechanically scraped fibers showed negligible nitrogen but a significant amount of oxygen on the surface. Furthermore, oxygen was present in C=O and COOH bonds as predicted by the oxidation mechanism. These findings cannot be explained by the notion that the surface is coated by a crosslinked protein-formaldehyde complex as proposed by Thames et al.³⁴, since the samples were never fixed in formalin.

Thames et al. recently published a study reporting that the surface of PP is coated by a crosslinked protein-formaldehyde complex.³⁵ However, both internal Ethicon studies from the 1980s as well as recently published papers have reported that the surface cracked layer is a complex composite of oxidized PP and adsorbed protein. Thus, while the Thames et al. cleaning protocol may be adequate for removing all of the adsorbed protein, it is not sufficient to characterize the composition and structure of the surface cracked layer. Alternative cleaning procedures that remove only the proteins in the “layer structure” should be used to avoid removing the “protein trapped by microcracks”³⁶ (Figure 8), which enables a more rigorous analysis of the surface cracked layer. Procedures previously used to clean PP sutures, hernia mesh, and pelvic mesh utilized sodium hypochlorite (bleach) solution, enzymatic solutions, or Soluene³⁷ to selectively remove proteins and tissue from the “layer structure” (Figure 1). Recommended protocols for analyzing explanted biomedical devices are described in ISO 12891. While no method is listed for cleaning PP explants, the standard recommends cleaning with sodium hypochlorite (bleach) solution for the closely related polyolefin, ultra-high molecular weight polyethylene.³⁸ In contrast, sonication is used to clean metals and jewels, remove dental plaque, and pulverize renal calculi.³⁹ Consequently, sonication for long periods of time (as reported by Thames et al.⁴⁰) can remove all detachable materials non-specifically, and is therefore not suitable for investigating the composition and structure of the surface

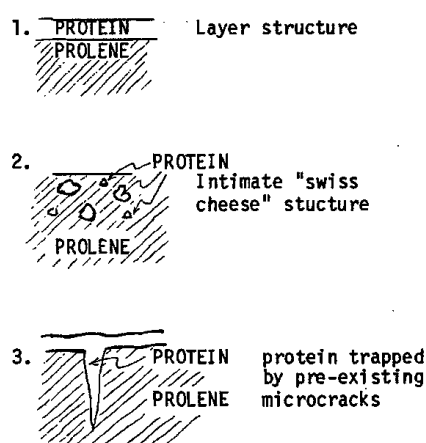


Figure 8. Three protein deposition mechanisms proposed by Dr. Peter Moy. ETH.MESH.15958445

³⁴ SF Thames, JB White, KL Ong. The myth: in vivo degradation of polypropylene-based meshes. *Int Urogynecol J* 28(2):285-297, 2017. M Thompson, SA Guelcher, R Bendavid, V Iakovlev, DR Ostergard. In vivo polypropylene mesh degradation is hardly a myth. *Int Urogynecol J* 28(2):333-335, 2017. SF Thames, JB White, KL Ong KL. Reply to "In vivo polypropylene mesh degradation is hardly a myth". *Int Urogynecol J* 28(2):337-338, 2017.

³⁵ SF Thames, JB White, KL Ong. The myth: in vivo degradation of polypropylene-based meshes. *Int Urogynecol J* 28(2):285-297, 2017. M Thompson, SA Guelcher, R Bendavid, V Iakovlev, DR Ostergard. In vivo polypropylene mesh degradation is hardly a myth. *Int Urogynecol J* 28(2):333-335, 2017. SF Thames, JB White, KL Ong KL. Reply to "In vivo polypropylene mesh degradation is hardly a myth". *Int Urogynecol J* 28(2):337-338, 2017.

³⁶ ETH.MESH.15958445.

³⁷ <http://www.perkinelmer.com/product/soluene-350-0-5-l-6003038>

³⁸ A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. In vivo oxidative degradation of polypropylene pelvic mesh. *Biomaterials* 73:131-141, 2015

³⁹ M Thompson, SA Guelcher, R Bendavid, V Iakovlev, DR Ostergard. In vivo polypropylene mesh degradation is hardly a myth. *Int Urogynecol J*. 28(2):333-335, 2017.

⁴⁰ SF Thames, JB White, KL Ong. The myth: in vivo degradation of polypropylene-based meshes. *Int Urogynecol J*. 28(2):285-297, 2017.

cracked layer. Dan Burkley, an Ethicon employee, noted the appearance of the surface scrapings from explanted Prolene sutures as resembling a “waxy snow”⁴¹, which implies a friable material and is in agreement with a recent study reporting that the surface of explanted PP mesh fibers is cracked and porous.⁴² Step #8 of the Thames et al. cleaning protocol comprised immersion in bleach solution in an ultrasonic bath for 1.5 h. This step is the second bleach treatment, after which the peaks ranging from 1500 – 1750 cm^{-1} , which are associated with carbonyl groups in proteins and oxidized PP, disappeared from the FTIR spectrum. This observation is consistent with the notion that sonication non-selectively debrides the surface of the PP fiber and removes all adherent material, including adsorbed proteins and oxidized PP. Thames et al. neglected to note that oxidized PP exhibits absorbance frequencies (1600 – 1699 cm^{-1} for carbonyl groups and 3409 cm^{-1} for hydroxyl groups) over ranges similar to those of the protein frequencies reported in their study, as described in internal Ethicon documents⁴³ and published studies.⁴⁴ Thus, Thames et al. cannot exclude the possibility that the cracked surface layer was composed of a complex mixture of oxidized PP and protein. Clave et al. noted that “FTIR absorption bands between 1,615 and 1,650 cm^{-1} could be attributed either to carboxylate carbonyl or to residual products of biological origin. Therefore, these results cannot confirm the formation of carboxyl groups in vivo.”⁴⁵ While Clave et al. did not speculate further on the composition of the cracked layer, it is important to note that their observations did not exclude the possibility of protein or oxidized PP. However, Thames et al. assumed that the cracked surface layer was protein on the basis of FTIR absorption frequencies associated with proteins (amide N-H stretching in the 3,300 cm^{-1} region and amide I carbonyl stretching in the region of 1,600–1,690 cm^{-1}) without noting the existence of overlapping peaks in the FTIR spectra of oxidized PP (1600 – 1699 cm^{-1} for carbonyl groups and 3409 cm^{-1} for hydroxyl groups).

More rigorous methods than those used by Thames et al. are required to correctly identify the composition of the cracked surface layer. Published studies as well as internal Ethicon studies have determined that the cracked surface layer contains oxidized PP. Mr. Burkley analyzed the surface scrapings removed from Prolene sutures explanted from patients using melting point analysis and FTIR, which led him to conclude that the surface contained oxidized PP and protein.⁴⁶ His experiments using Soluene to selectively extract tissue from the surface led him to conclude that Soluene could remove the protein adhering to the surface of the fibers but not protein that had penetrated into the pores.⁴⁷ Iakovlev et al. used microscopic analysis of axial cross sections of explanted PP mesh fibers to show that surface cracks were predominantly oxidized PP.⁴⁸ Imel et al. used EDS⁴⁹ and Talley et al. used XPS⁵⁰ to identify regions of PP fibers from explanted mesh

⁴¹ ETH.MESH.12831391

⁴² VV Iakovlev, SA Guelcher, R Bendavid. *In vivo* degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Appl Biomed Mater Res B: Appl Biomater* 105(2):237-248, 2017.

⁴³ ETH.MESH.12831391; ETH.MESH.15958452; Memo to Dr. AJ Melveger from Dr. P Moy, Prolene Microcracking, November 5, 1984.

⁴⁴ AD Talley, BR Rogers, V Iakovlev, RF Dunn, and SA Guelcher. Oxidation and degradation of polypropylene transvaginal mesh. *J Biomater Sci Polym Ed* 28(5):444-458, 2017.

⁴⁵ A Clave, H Yahi, J-C Hammou, S Montanari, P Gounon, H Clave. Polypropylene as a reinforcement in pelvic surgery is not inert: comparative analysis of 100 explants. *Int Urogynecol J* 21:261-270, 2010.

⁴⁶ ETH.MESH.12831391; ETH.MESH.15958452

⁴⁷ ETH.MESH.15958336

⁴⁸ VV Iakovlev, SA Guelcher, R Bendavid. *In vivo* degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Biomed Mater Res: Part B Appl Biomater* 105(2):237-248, 2017.

⁴⁹ A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. In vivo oxidative degradation of polypropylene pelvic mesh. *Biomaterials* 73:131-141, 2015.

that showed evidence of oxygen on the surface but not nitrogen, which can be explained by oxidation but not protein adsorption. Thames et al. could have used any of these methods to independently characterize the composition of the cracked surface layer rather than simply assume it was protein on the basis of FTIR measurements. Without a more rigorous analysis of the cracked surface layer, it cannot be concluded that it did not include oxidized PP.

3) The dynamic environment where the Prolene mesh is implanted coupled with the foreign body reaction leads to oxidation, chain scission, reduction in molecular weight, embrittlement, degradation, flaking, pitting, and cracking;

In an early study, Prolene sutures implanted for 1 – 2 years in a canine thoracoabdominal bypass model showed evidence of transverse cracks and peeling (Mary 1998).⁵¹ Several more recent studies have reported degradation of explanted PP pelvic mesh. In the first study characterizing explanted pelvic mesh, Clavé et al. reported that 42% of the explants showed evidence of chronic inflammation, characterized by an infiltrate of mononuclear cells and FGBCs. SEM analysis revealed that the implants were degraded, and that degradation was observed in meshes that had been implanted for at least 3 months.⁵²

In 1985, Ethicon implanted 24 beagles with PROLENE, PVDF, Ethilon, and Novafil sutures subcutaneously in a 10-year study. The study was ended at 7 years due to the unexpected death of one of the dogs at 6 years and 10.5 months. At 7 years, Dr. Lindemann noted that “degradation in Prolene is still increasing”⁵³ and that three of the seven explanted Prolene sutures showed evidence of surface cracking.⁵⁴ Mr. Burkley noted that IR spectra for cracked Prolene specimens “showed possible evidence of slight oxidation (a broadened weak absorbance at about 1650 cm⁻¹).”⁵⁵ Differences in the crosshead (XH) speed of the testing device can explain the increased elongation at break reported for the 7-year explants, as summarized in Table 1 below:

Table 1. Crosshead speed used to measure tensile properties of the Prolene sutures explanted from dogs.

⁵⁰ AD Talley, BR Rogers, V Iakovlev, RF Dunn, and SA Guelcher. Oxidation and degradation of polypropylene transvaginal mesh. *J Biomater Sci Polym Ed* 28(5):444-458, 2017.

⁵¹ C Mary, Y Marois, MW King, G Laroche, Y Douville, L Martin, R Guidoin. Comparison of the In Vivo Behaviour of Polyvinylidene Fluoride and Polypropylene Sutures Used in Vascular Surgery. *ASAIO Journal* 44:199-206, 1998.

⁵² A Clave, H Yahi, J-C Hammou, S Montanari, P Gounon, H Clave. Polypropylene as a reinforcement in pelvic surgery is not inert: comparative analysis of 100 explants. *Int Urogynecol J* 21:261-270, 2010.

⁵³ ETH.MESH.09888187.

⁵⁴ ETH.MESH.09888187.

⁵⁵ ETH.MESH.09888187.

Reference	Date	Action
ETH.MESH.11336184	5/30/85	XH speed was specified as 5 in / min for all products in the protocol
ETH.MESH.11336184	8/21/87	XH speed was changed to 10 in / min for all products
ETH.MESH.11336071	8/18/88	XH speed was reported as 1 in / min for the 1 yr and 2 yr Prolene explants and 5 in / min for all other 1- and 2-yr explants
ETH.MESH.11336071	9/20/88	XH speed was reported as 10 in /min for all products in the 2-yr interim report
ETH.MESH.05453719	10/19/92	XH speed was reported as 1 in / min for the 7-yr Prolene explants and 5 in / min for all other 7-yr explants

The crosshead speed is a measure of the rate at which the test specimen is strained. As the crosshead speed decreases, the tensile modulus of the polymer being tested decreases while the elongation rate increases.⁵⁶ Thus, the crosshead speed is an important experimental parameter, but it is not clear what the crosshead speed was at each of the experimental conditions. As shown in Table 1, the crosshead speed was initially specified as 5 in / min in the original animal protocol. Two years later, the crosshead speed was changed to 10 in / min for all products. However, other documents state that crosshead speeds different from those specified in the protocol were used for 1-, 2-, and 7-year explants, and that these speeds were different for Prolene sutures compared to the other sutures.⁵⁷ Therefore, I find the tensile testing of sutures from the dog study to be unreliable due to these discrepancies in the crosshead speeds used for the testing.

In the study that I co-authored with Dr. Iakovlev⁵⁸, a layer of degraded PP was observed by optimal microscopy near the surface of the fibers in the explanted mesh (Figure 7). Micro-cracks were present in the degraded PP layer. Degradation and cracking of the polypropylene fibers was observed as early as 18 months for a cohort of 23 explanted PP SUI devices.

Mays et al. also observed degradation of fiber in explanted PP mesh using SEM. Using a combination of SEM and EDS, the authors were able to distinguish between fibers that were clean and those that were coated with biological material. Explanted fibers were observed that showed evidence of severe transverse cracks (Figure 7), which was accompanied by oxidative degradation of the fibers. The authors identified the mechanism of PP degradation as comprising the following steps: infiltration of inflammatory cells that secrete ROS in close proximity to the PP mesh fibers, oxidative degradation of the PP fibers characterized by the appearance of hydroxyl and carbonyl groups in the FTIR spectra, a reduction in molecular weight, embrittlement, cracking, and fragmentation of the PP fibers.

4) PP mesh is known to fray under tension and release particles while being handled

⁵⁶ EA Campo. *Selection of Polymeric Material: How to Select Design Properties from Different Standards*. A volume in *Plastics Design Library*, William Andrew Applied Science Publishers, Norwich, NY 2008.

⁵⁷ ETH.MESH.11336071; ETH.MESH.05453719.

⁵⁸ VV Iakovlev, SA Guelcher, R Bendavid. In vivo degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *Journal of Applied Biomedical Materials Research B: Applied Biomaterials* 105(2):237-248, 2017.

and implanted. The human body does not stop responding to these particles or to the PP mesh unless the product is removed in its entirety;

As an example of how oxidation of an implanted biomaterial affects its performance, poly(ether urethane)s (PEUs) were used as pacemaker lead insulation due to their improved mechanical properties as compared to silicone rubber. While PEU elastomers were believed to be biocompatible for many years, they are now known to undergo environmental stress cracking due to oxidative degradation of the polyether component and subsequent loss in molecular weight.⁵⁹ Adherent macrophages and FBCGs were shown to be responsible for environmental stress cracking. Thus oxidative degradation and environmental stress cracking comprise a vicious cycle in which oxidative degradation drives the embrittlement of the polymer surface and its subsequent cracking, which in turn exposes new surfaces of the material to oxidative degradation. Another study has shown that ROS actively degrades lysine-derived poly(ester urethane)s *in vivo* by an oxidative mechanism.⁶⁰ Thus, oxidative degradation of biomaterials *in vivo* in response to ROS secreted by inflammatory cells is well known.

Since the foreign body reaction is present at the biomaterial surface for the lifetime of the implant, the oxidative process is ongoing as long as the implant is present.⁶¹ Considering the ongoing foreign body reaction as well as the known susceptibility of PP to oxidation, the mechanical and physical properties of Ethicon's PP mesh will change after it is implanted.

In addition, the properties of Ethicon's PP mesh have been shown to change under tension and while the mesh is being handled.⁶² The medical literature and Ethicon's internal studies have reported that particles are lost or shed from the TVT mesh while it is in the box and while it is being implanted.⁶³ The foreign body reaction to shed particles will be similar to that for the TVT mesh. The body will not stop responding to any particles that are shed inside the body during implantation until those particles are removed in their entirety.

- 5) Ethicon's pelvic meshes are intended to last for the lifetime of the patient, but the presence of antioxidants does not permanently protect the PP against degradation, and thus it is not possible to guarantee that these meshes will perform their intended function after implantation.**

Although PP can never be considered inert, it is stabilized against oxidation by adding antioxidants to the molten polymer, which are intended to act as scavengers that will react

⁵⁹ *Id.*

⁶⁰ AE Hafeman, KJ Zienkiewicz, AL Zachman, HJ Sung, LB Nanney, JM Davidson, SA Guelcher. Characterization of degradation mechanisms of biodegradable lysine-derived aliphatic polyurethanes. *Biomaterials* 32(2):419-29, 2011; J Martin, MK Gupta, JM Page, F Yu, JM Davidson, SA Guelcher, CL Duvall. Synthesis of a Porous, Biocompatible Tissue Engineering Scaffold Selectively Degraded by Cell-Generated Reactive Oxygen Species. *Biomaterials* 35(12):3766-76, 2014.

⁶¹ JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol* 20(2): 86-100, 2008.

⁶² ETH.MESH.01813975; ETH.MESH.01317515; ETH.MESH.03905472; ETH.MESH.00541379; ETH.MESH.00863391.

⁶³ *Id.*

with oxidative species.⁶⁴ The enduring nature of the foreign body reaction emphasizes the need for antioxidants to be added to biomaterials such that the time to oxidation, degradation, and embrittlement is extended.⁶⁵ PP in its pure (i.e., unstabilized) form degrades rapidly *in vivo*, with an induction period of only 108 days⁶⁶, and carbonyl groups were detected in unstabilized PP by infrared spectroscopy within 50 – 90 days.⁶⁷ Liebert et al. also tested stabilized PP in the hamster subcutaneous implant model. Oxidation of stabilized PP was observed, but the experiment ended at 100 days, at which time induction had not been observed for stabilized PP filaments. Consequently, the eventual *in vivo* induction time for stabilized PP has not been reported.

Stabilization with antioxidants is not permanent, since the purpose of using antioxidants is to react with any oxidative species (such as ROS) to prevent their reaction with PP.⁶⁸ These stabilizers are distributed throughout the PP, however, and can only protect the polymer if they are in the proper location and only until they are exhausted. The antioxidant package must be optimized for the intended use to achieve maximum service life of the polymer. Neither the Santonox R nor the dilaurothiodipropionate (DLTDP) antioxidant in the Prolene resin used to manufacture Prolene mesh⁶⁹ is designed to protect against the ROS secreted by inflammatory cells *in vivo*. Santonox R is a hindered phenolic antioxidant designed to protect Prolene during high-temperature processing (compounding and extrusion), while DLTDP is designed to protect Prolene from oxidation during long-term storage. Because *in vivo* oxidation and degradation are ongoing in response to the foreign body reaction, the antioxidant will eventually be depleted, resulting in oxidation and degradation of the PP mesh and changes to its properties over time. This cycle of depletion of antioxidants through reaction with ROS followed by the eventual degradation of the surface of the mesh will not stop until all of the mesh is removed, since cracking exposes new surfaces to ROS and the reaction begins anew.⁷⁰

In a manuscript recently accepted for publication, I have reported that TVT, Advantage (Boston Scientific), and Lynx (Boston Scientific) PP meshes, all of which are stabilized with antioxidants, oxidize *in vitro* when incubated in oxidative medium that mimics the reactive oxygen species (ROS) secreted by adherent inflammatory cells.⁷¹ FTIR spectra of

⁶⁴ E. Rene de la Rie. Polymer Stabilizers. A Survey with Reference to Possible Applications in the Conservation Field. *Studies in Conservation* 33:9-22, 1988.

⁶⁵ JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol* 20(2): 86–100, 2008.

⁶⁶ Liebert et al. Subcutaneous implants of PP filaments. *JBMR* 10:939-51, 1976.

⁶⁷ *Id.*

⁶⁸ *Id.*

⁶⁹ ETH.MESH.02268620

⁷⁰ JM Anderson, A Rodriguez, DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol* 20(2): 86–100, 2008.

⁷¹ QH Zhao, AK McNally, KR Rubin, M Renier, Y Wu, V Rose-Caprara, JM Anderson, A Hiltner, P Urbanski, K Stokes. Human plasma macroglobulin promotes in vitro oxidative stress cracking of Pellethane 2363-80A: In vivo and in vitro correlations. *J Biomed Mater Res* 27: 379-389, 1993. AE Hafeman, KJ Zienkiewicz, AL Zachman, HJ Sung, LB Nanney, JM Davidson, SA Guelcher. Characterization of degradation mechanisms of biodegradable lysine-derived aliphatic polyurethanes. *Biomaterials* 32(2):419-29, 2011. JL Martin, MK Gupta, JM Page, F Yu, JM Davidson, SA Guelcher, CL Duvall. Synthesis of a Porous, Biocompatible Tissue Engineering Scaffold Selectively Degraded by Cell-Generated Reactive Oxygen Species. *Biomaterials* 35(12):3766-76, 2014. MAP McEnery, S Lu, MK Gupta, KJ Zienkiewicz, JC Wenke, K Kalpakci, D Shimko, CL Duvall, SA Guelcher. Resorbable Poly(thioketal urethane)/Ceramic Composite Bone Cements with Bone-Like Strength. *RSC Advances* 6:109414 - 109424, 2016. JR Martin, CE

PP incubated in oxidative medium for 5 weeks revealed evidence of carbonyl and hydroxyl bonds as predicted by the oxidation mechanism. These findings show that antioxidants cannot stabilize PP mesh indefinitely.

- 6) The effects of oxidation on the stability of Prolene were known to Ethicon prior to launching its SUI and POP devices, but the company did not consider the risks associated with polypropylene oxidation on the stability of Prolene mesh, to the detriment of patients implanted with the devices.**

Ethicon first reported evidence of Prolene oxidation and degradation in internal documents from the 1980s. These documents report evidence of chronic inflammation, oxidation, and degradation (micro-cracking) of Prolene sutures similar to that published in the scientific literature described above. Several relevant studies are reviewed in greater detail below.

In 1981, the depth of surface cracks was measured for explanted cardiovascular and ophthalmic Prolene sutures.⁷² The crack depth varied from 0.5 – 4.5 microns. Another memo in 1983 reported cracking of explanted Prolene sutures.⁷³ One of the explanted sutures showed only 54% of its original strength. The memo noted that the histological evaluation of explanted sutures was consistent with previous studies, characterized by a foreign body reaction and a “degraded acellular infiltrate.” This document also refers to a Prolene Microcrack Committee. Thus, Ethicon was sufficiently aware of Prolene surface cracking to form a committee to investigate the mechanism of cracking.

Two memos written in 1984 investigated the cause of microcracking of explanted PP sutures from both ophthalmic and cardiovascular applications⁷⁴. Sutures that were in the body for more than two years exhibited surface or severe transverse cracks. The thickness of the crack layer ranged from 2 – 5 microns thick. Dr. Peter Moy recognized in a November 5, 1984 report that “oxidative degradation is another mechanism through which transverse cracks may be produced on oriented fibers.”⁷⁵ In an attempt to reproduce the observed cracking *in vitro*, Prolene sutures were incubated in aqueous 30% hydrogen peroxide for up to 1 year. Despite the fact that transverse cracks were not observed, infrared spectroscopy revealed evidence of oxidation products, which prompted Dr. Moy to note that “the possibility of a highly specific *in vivo* oxidation process remains.” These findings are consistent with the foreign body reaction, which produces ROS stronger than hydrogen peroxide.⁷⁶ If treatment with 30% hydrogen peroxide caused oxidation of the PP suture (as reported by Dr. Moy), then ROS secreted by adherent macrophages would also be expected to cause oxidation. Dr. Moy also cited thermal stability and electron microdiffraction data supporting his hypothesis that at least a portion of the cracked layer contained protein. He recommended that an additional study was necessary to test this hypothesis by performing TEM analysis of known oxidized Prolene samples. Another memo dated November 13, 1984, reported that Prolene microcracks were evaluated by

Nelson, MK Gupta, F Yu, KM Hocking, JM Davidson, SA Guelcher, CL Duvall. Local delivery of PHD2 siRNA from ROS-degradable scaffolds to promote diabetic wound healing. *Adv Healthc Mater* 5(21):2751-2757, 2016.

⁷² ETH.MESH.12831405.

⁷³ ETH.MESH.15955438-15955473.

⁷⁴ ETH.MESH.15958452, ETH.MESH.15406978, ETH.MESH.15958470

⁷⁵ ETH.MESH.1595843

⁷⁶ QH Zhao, AK McNally, KR Rubin, M Renier, Y Wu, V Rose-Caprara, JM Anderson, A Hiltner, P Urbanski, K Stokes. Human plasma macroglobulin promotes *in vitro* oxidative stress cracking of Pellethane 2363-80A: *In vivo* and *in vitro* correlations. *J Biomed Mater Res* 27: 379-389, 1993.

Attenuated Total Reflectance (ATR) and FTIR.⁷⁷ These studies found that the cracked Prolene surface is a composite of oxidized polypropylene and adsorbed protein. Surface protein was removed with Soluene treatment, but adsorbed protein remained in the microcracks. Thus, the November 13, 1984 memo by Dan Burkley concludes that the cracked layer contained both oxidized Prolene as well as protein.

In 1985, a series of experiments was proposed, including microscopic FTIR, TEM, and histology, to determine the clinical functionality of cracked sutures, the cracking mechanism, and effects of antioxidant concentration.⁷⁸ Dr. Moy further noted that laboratory experiments had not yet replicated the cracking observed in explants, and proposed a systematic evaluation of explanted Prolene sutures.

In 1987, Professor Guidoin provided Ethicon with his explanted sutures, which had been cleaned using a bleach solution as explained in Mr. Burkley's laboratory notebook.⁷⁹ SEM images of sutures explanted after 8 years revealed evidence of severe cracking. Another cohort of explanted sutures was scraped with a needle and the scrapings tested by calorimetry and FTIR. The waxy scrapings showed a melting point of 147 – 156°C, which is comparable to that of degraded Prolene. Non-degraded Prolene melts over the range 155 – 165°C. Scrapings were also melted on a KBr window to obtain FTIR spectra, which showed peaks associated with β -keto esters known to be formed during PP oxidation. Mr. Burkley noted in his notebook and memo that “no protein species or peptide bonds were suggested.” A memo reporting on a follow-up meeting confirmed the findings that no protein was found on the surface and that Prolene degradation occurred on the surface of the fibers.⁸⁰ Several follow-up studies were proposed, including investigating the relationship between antioxidant concentration and polypropylene degradation and cracking. However, to my knowledge these studies were not performed.

In 1991, a 91-day rat subcutaneous implantation study was performed to assess the tissue reaction for several PP-based surgical meshes, including the Prolene mesh used in the SUI and POP devices.⁸¹ All meshes, including Prolene and Prolene Soft, showed evidence of chronic inflammation at 7 and 91 days. Drs. Barbolt and Hutchinson concluded that all meshes showed evidence of a mild inflammatory reaction and infiltration of connective tissue. Furthermore, images of histological sections revealed evidence of adherent macrophages on the surface of the Prolene fibers.

⁷⁷ ETH.MESH.15958336

⁷⁸ ETH.MESH.15958445

⁷⁹ ETH.MESH.00000367, ETH.MESH.12831391

⁸⁰ ETH.MESH.12831407

⁸¹ ETH.MESH. 02319001, ETH.MESH.01425079

As noted above, Ethicon researchers sought to replicate the surface cracking of Prolene sutures in an *in vitro* experiment. In the 1990s, the effects of the foreign body reaction on biomedical implants were first elucidated. All implantable medical devices are susceptible to the dynamic nature of the environment in which they are implanted. Environmental stress cracking of implanted biomaterials is controlled by three factors: (1) residual stress in the biomaterial, (2) a source of chemical degradation in the body, and (3) the chemical structure of the biomaterial.⁸² Poly(ether urethane)s used as pacemaker lead insulation are an example of how oxidation of an implanted biomaterial can lead to Environmental Stress Cracking (ESC) and device failure. While poly(ether urethane) elastomers were believed to be biocompatible for many years, they are now known to undergo ESC due to oxidative degradation of the polyether component and subsequent loss in molecular weight.⁸³ As shown in Figure 9, adherent macrophages and FBCGs were responsible for environmental stress cracking of poly(ether urethane)s *in vivo*.⁸⁴ A later study found that *in vivo* stress cracking of this poly(ether urethane) was reproduced *in vitro* by treating pre-stressed polymer specimens with an oxidative medium (10% hydrogen peroxide with 0.10 M cobalt chloride).⁸⁵ The cobalt chloride catalyzes the decomposition of the hydrogen peroxide to form hydroxyl radicals, a form of ROS that attacks the polymer. Under these conditions simulating the isolated microenvironment between the surface of the biomaterial and the cell, *in vitro* stress cracking was similar in appearance to that observed *in vivo*. Furthermore, infrared spectroscopy showed that ROS participated in the oxidative degradation process.⁸⁶ Thus, oxidative degradation and environmental stress cracking have a synergistic effect on the failure of poly(ether urethane) catheter lead insulation, by which oxidative degradation drives the embrittlement of the polymer surface and its subsequent cracking, which in turn exposes new surfaces of the material to oxidative degradation and

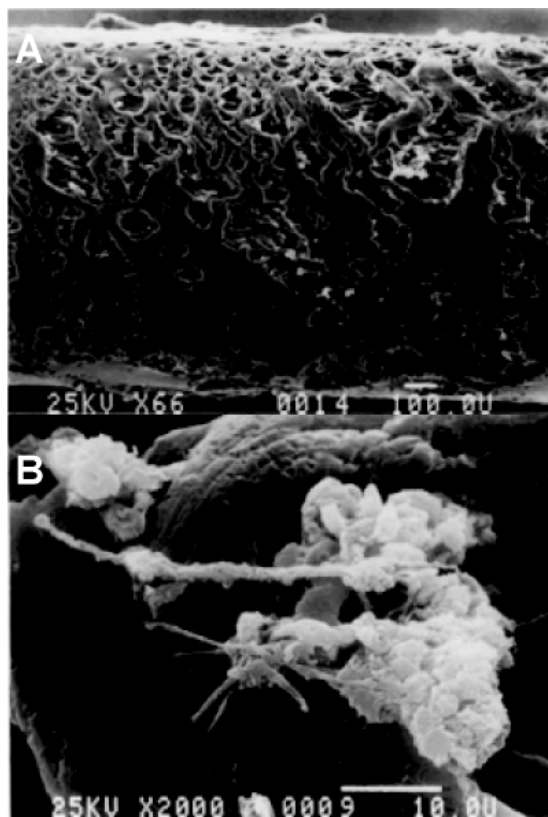


Figure 9. (A) SEM photograph of pre-stressed Pellethane 80A specimen implanted for 5 weeks. The specimen had severe cracking. Original magnification x66. (B) SEM photograph (at higher magnification) of pre-stressed Pellethane 80A specimen implanted for 5 weeks. Cellular adhesion was present. Original magnification x2000. From Zhao et al. *JBMR* 24:621, 1990.

⁸² JM Anderson et al. Cellular interactions with biomaterials: in vivo cracking of pre-stressed Pellethane 2363-80A. *JBMR* 24: 621-37, 1990.

⁸³ *Id.*

⁸⁴ JM Anderson et al. Cellular interactions with biomaterials: in vivo cracking of pre-stressed Pellethane 2363-80A. *JBMR* 24: 621-37, 1990.

⁸⁵ QH Zhao, AK McNally, KR Rubin, M Renier, Y Wu, V Rose-Caprara, JM Anderson, A Hiltner, P Urbanski, K Stokes. Human plasma macroglobulin promotes in vitro oxidative stress cracking of Pellethane 2363-80A: In vivo and in vitro correlations. *J Biomed Mater Res* 27: 379-389, 1993.

⁸⁶ MJ Wiggins, B Wilkoff, JM Anderson, A Hiltner. Biodegradation of polyether polyurethane inner insulation in bipolar pacemaker leads. *J Biomed Mater Res* 58(3):302-7, 2001.

ultimately clinical device failure.⁸⁷ Similar to poly(ether urethane)s, PP is susceptible to oxidation, which results in chain scission, loss of ductility (e.g., embrittlement),⁸⁸ and degradation, such as pitting, peeling, and cracking⁸⁹. Embrittlement occurs at a very low conversion in the chain scission process, and surface embrittlement of the PP fibers leads to crack initiation. Mechanical stress on the fibers will in turn enhance stress cracking and expose new PP surface to the oxidative environment. I have published two papers in the scientific journal *Biomaterials*, one in 2011 and one in 2014, using the same 20% H₂O₂ /0.1 M cobalt chloride system to measure the oxidative degradation rate of poly(ester urethane) and poly(thioketal urethane) scaffolds. Thus, this *in vitro* oxidative degradation test is well established in the scientific literature, and was available to Ethicon at the time it developed the SUI and POP devices. However, to my knowledge, this test was never done.

Ethicon has also been made aware of the specific risks inherent to using PP in an implantable medical device through the Material Safety Data Sheet (MSDS), which stated that PP is incompatible with strong oxidizers.⁹⁰ As explained above, implanted mesh is exposed to reactive oxygen species, which are strong oxidizers, as a result of the foreign body reaction.

The report from Mesh Repair of Uterovaginal Prolapse meeting in May 1997 noted that an ideal mesh would have lower density compared to that of the TVT to minimize the foreign body reaction.⁹¹ Similar concerns were noted in a discussion document for the design of new mesh for prolapse repair, in which it was noted that the mesh used in the TVT is not the ideal material for anterior prolapse, and that the amount of foreign body should be minimized to reduce the risk of complications.⁹²

The hernia literature also provides evidence that the foreign body reaction alters polypropylene *in vivo*. In a study evaluating non-degradable meshes explanted from 17 patients that had surgery for repair of abdominal wall defects, a foreign body reaction characterized by granulation tissue and inflammatory cells 3 – 24 months post-implantation was seen.⁹³ The PP meshes from this study showed more inflammatory cells and fibroblasts near the mesh interface when compared to PTFE and polyester.

Despite internal and published studies to the contrary, Ethicon documents further indicate that their sales force was instructed to "[r]eassure [surgeons] that PROLENE is proven to be inert and there are hundreds of papers going back 25 years to reinforce this point."⁹⁴ However, Daniel F. Burkley, a Principal Scientist at Ethicon, testified that in his 34 years at the company, he was only familiar with one study that was conducted regarding the changes that occurred due to oxidative degradation of explanted polypropylene suture or

⁸⁷ JM Anderson, A Rodriguez, and DT Chang. Foreign Body Reaction to Biomaterials. *Semin Immunol* 20(2):86–100, 2008.

⁸⁸ Fayolle et al. Initial steps and embrittlement in the thermal oxidation of stabilized polypropylene films. *Polym Degrad Stability* 75:123-9, 2002.

⁸⁹ VV Iakovlev, ET Carey, J Steege. Pathology of Explanted Transvaginal Meshes. *Int. J. Medical, Health, Pharmaceutical and Biomedical Eng.* 8(9):510-513, 2014.

⁹⁰ ETH.MESH.05439518

⁹¹ ETH.MESH.12006257

⁹² ETH.MESH.12009027

⁹³ U Klinge, B Klosterhalfen, M. Muller, V Schumpelick. Foreign Body Reaction to Meshes Used for the Repair of Abdominal Wall Hernias. *Eur J Surg* 165:665–673, 1999.

⁹⁴ ETH.MESH. 00865322

mesh.⁹⁵ Mr. Burkley also testified that this study showed that changes due to oxidation were still progressing after seven years of implantation.⁹⁶

7) PP mesh is not inert and its properties change after implantation, which can lead to adverse events in an implantee; using heavy-weight mesh directly correlates to more PP being exposed to the foreign body reaction and greater changes after implantation, which increases the risk of complications.

The literature has confirmed that the properties of PP mesh change after implantation, causing adverse events like, pain, scarring and inflammation. In addition, Ethicon employees and consultants, both before and after the TVT was launched, have noted that heavy-weight meshes like the TVT comprise significantly more polypropylene than sutures or light-weight meshes, and therefore the foreign body reaction and resulting changes on the surface of the TVT device will be much greater than that for a lightweight mesh or a non-load bearing suture.⁹⁷ These findings are supported by the conclusions drawn by external consultants and Ethicon employees, as well as the available scientific literature reporting PP oxidation in response to cell-secreted ROS and complications associated with the mesh used in the TVT.⁹⁸

More recently, Wood et al. published a comparison of three different explanted synthetic meshes (polypropylene, expanded polytetrafluoroethylene (ePTFE), and polyethylene terephthalate (PET)) from a single patient who had undergone three recurrent ventral hernia repairs.⁹⁹ Implantation times for the meshes were 3 years for the PP and PET meshes and 2 years for the ePTFE mesh. SEM images of explanted PP mesh “showed significant surface cracking” while the PET and ePTFE meshes did not. FTIR analysis also confirmed PP degradation from “free radical formation and oxidation of the polypropylene mesh while *in vivo*.”

The Wood study supports the conclusions published by Clavé et al., which examined explanted pelvic meshes for degradation. Clavé reported that 42% of the explants showed evidence of chronic inflammation, characterized by an infiltrate of mononuclear cells and FGBCs. SEM analysis revealed that the implants were degraded, and that degradation was observed in meshes that had been implanted for at least 3 months.¹⁰⁰

The findings of the Clavé study findings reinforced work done by Costello et al., who reported PP mesh oxidation and embrittlement as being a cause of mesh degradation and

⁹⁵ Burkley Deposition 05/23/2013 P.312:23-313:24

⁹⁶ Burkley Deposition 05/23/2013 P.315:8-13

⁹⁷ Are Meshes With Lightweight Construction Strong Enough?; Jorge L. Holste; *ETHICON GmbH, R&D Europe, D-22841, Norderstedt, Germany*; J. Otto, E. Kaldenhoff, R. Kirschner-Hermanns, T. Muhl, U. Klinge, W.S. Cobb, K.W. Kercher, and B.T. Heniford. The Argument for Lightweight Polypropylene Mesh in Hernia Repair. *Surg Innov.* 12(1):63-9, 2005.

⁹⁸ ETH.MESH.05479411, ETH.MESH.07192929, ETH.MESH.07192412.

⁹⁹ AJ Wood, et al. Materials Characterization and Histological Analysis of Explanted Polypropylene, PTFE, and PET hernia meshes from an Individual Patient. *J Mater Sci Mater Med* 24(4): 1113-1122, 2013.

¹⁰⁰ A Clave, H Yahi, J-C Hammou, S Montanari, P Gounon, H Clave Polypropylene as a reinforcement in pelvic surgery is not inert: comparative analysis of 100 explants. *Int Urogynecol J* 21:261-270, 2010.

complications *in vivo*.¹⁰¹ Costello derived his conclusions from comparisons made between pristine and explanted samples via molecular weight, SEM imaging, and compliance testing. Those authors reported that all three of these methods confirmed that PP mesh had degraded *in vivo*, most likely by oxidation.¹⁰²

Another study investigated 14 explanted hernia mesh samples observed by SEM that 85% of the samples showed evidence of cracking, fissures, and peeling.¹⁰³ After host tissue was removed, the mesh samples remained folded and contracted, evidencing that mesh samples were permanently changed after implantation.

In a 2015 study I co-authored with Dr. Vladimir Iakovlev analyzing 164 explanted PP pelvic meshes, we reported the presence of adherent inflammatory cells expressing the oxidative enzyme myeloperoxidase, degradation of polypropylene, and micro-cracking near the surface of the polypropylene fibers. Degradation of explanted meshes was observed as early as 18 months.¹⁰⁴ Similar findings were reported by Mays et al., who observed oxidative degradation and transverse cracking of explanted PP pelvic mesh.¹⁰⁵

Most importantly, these studies linked complaints of chronic pain and sclerosis to the foreign body reaction to implanted PP mesh and the consequent degradation and micro-cracking near the surface of PP fibers. These principles also apply to PP particles shed from the mesh during implantation, which is consistent with the testimony of Ethicon medical director Piet Hinoul that when particle loss occurs during implantation, the released particles result in inflammation that can cause pain.¹⁰⁶

Large animal models, such as sheep, enable evaluation of PP mesh at longer time points and under conditions more representative of the clinical environment for SUI and POP repair.¹⁰⁷ A pilot study evaluated Prolene mesh implanted vaginally in sheep at 6 and 12 weeks.¹⁰⁸ The incidence of vaginal erosion was observed to be 33%. Macrophages and foreign body giant cells were also observed at 12 weeks. Two more recent studies have investigated differences between PP meshes implanted vaginally and abdominally using a sheep model.¹⁰⁹ PP mesh implanted vaginally showed more contraction and exposures,

¹⁰¹ CR Costello, SL Bachman, SA Grant, DS Cleveland, TS Loy, BJ Ramshaw. Characterization of heavyweight and lightweight polypropylene prosthetic mesh explants from a single patient. *Surg Innov.* 14:168–176, 2007; CR Costello, SL Bachman, SA Grant. Materials characterization of explanted polypropylene hernia meshes. *J Biomed Mater Res Part B: Appl Biomater* 83B:44-49, 2007.

¹⁰² *Id.*

¹⁰³ *Id.*

¹⁰⁴ VV Iakovlev, SA Guelcher, R Bendavid. In vivo degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Appl Biomed Mater Res B: Appl Biomater* 105(2):237-248, 2017.

¹⁰⁵ A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. In vivo oxidative degradation of polypropylene pelvic mesh. *Biomaterials* 73:131-141, 2015.

¹⁰⁶ Trial Testimony of Piet Hinoul, Batiste v. Ethicon, page 26-28

¹⁰⁷ A Feola, M Endo, I Urbankova, J Vlácil, T Deprest, S Bettin, B Klosterhalfen, J Deprest. Host reaction to vaginally inserted collagen containing polypropylene implants in sheep. *Am J Obstet Gynecol* 212:474.e1-8, 2015.

¹⁰⁸ R de Tayrac, A Alves, M Thérin M. Collagen-coated vs noncoated low-weight polypropylene meshes in a sheep model for vaginal surgery. A pilot study. *Int Urogynecol J Pelvic Floor Dysfunct.* 18(5):513-20, 2007.

¹⁰⁹ S Manodoro, M Endo, P Uvin, M Albersen, J Vlácil, A Engels, B Schmidt, D De Ridder, A Feola, J Deprest. Graft-related complications and biaxial tensiometry following experimental

which are both mesh-related complications, than mesh implanted abdominally.¹¹⁰ The authors further noted that the 15% incidence of vaginal exposures in all animals was comparable to that observed clinically, and found that mesh-related complications can be induced by vaginal mesh implantation. Contraction and folding, which have also been associated clinically with pain,¹¹¹ were also observed to be higher for vaginally implanted mesh compared to that implanted abdominally. In a follow-up study, the same authors investigated the effects of a collagen coating on mesh complications and made similar findings.¹¹² Vaginal exposures were observed in 33%, while no abdominal exposures were observed. Macrophages and foreign body giant cells were observed at 60 and 180 days in both vaginal and abdominal meshes. These findings led the authors to conclude that the sheep is an effective model to study complications of vaginal mesh. They further noted that the differential wound healing response and mechanical forces between the vaginal and abdominal wall environments may be responsible for the differences in mesh-related complications between the two implantation sites. Ethicon could have performed a similar sheep study at any time before or after the launch of its any of its mesh products to investigate the incidence of similar mesh-related complications. However, to my knowledge these studies have not been done.

Ethicon documents indicate that the company was aware of the Costello article in 2007, but never considered the effect of PP oxidation during these meshes design or product lifecycle. An Ethicon Medical Affairs employee, Tom Divilio, M.D., indicated that the Costello authors were "challenging our perception of polypropylene as an 'inert' material after implantation." He went on to note that "I think it's important that we understand what they are seeing as this group has a well-funded lab that will be looking at explanted mesh in great volume over the next couple of years and our current concepts are going to be challenged. Would appreciate it if we could think of some study designs that would confirm or refute their assumptions."¹¹³ In 2012, Ethicon responded to a request by a British regulatory agency to explain how the 2010 publication by Clave et al impacts the performance of their products.¹¹⁴ In this document, Ethicon noted "[we] are not aware of any findings that would impact the clinical performance of polypropylene monofilament"¹¹⁵, and that "[p]olymers may be subject to surface degradation by these

vaginal implantation of flat mesh of variable dimensions. *BJOG* 120(2):244-50, 2013.; A Feola, M Endo, I Urbankova, J Vlacil, T Deprest, S Bettin, B Klosterhalfen, J Deprest. Host reaction to vaginally inserted collagen containing polypropylene implants in sheep. *Am J Obstet Gynecol* 212:474.e1-8, 2015.

¹¹⁰ S Manodoro, M Endo, P Uvin, M Albersen, J Vlácil, A Engels, B Schmidt, D De Ridder, A Feola, J Deprest. Graft-related complications and biaxial tensiometry following experimental vaginal implantation of flat mesh of variable dimensions. *BJOG* 120(2):244-50, 2013.

¹¹¹ BT Haylen, RM Freeman, SE Swift, M Cosson, GW Davila, J Deprest et al. An International Urogynecological Association (IUGA)/ International Continence Society (ICS) joint terminology and classification of the complications related directly to the insertion of prostheses (meshes, implants, tapes) and grafts in female pelvic floor surgery. *Neurourol Urodyn* 30:2-12, 2011.

¹¹² Haylen BT, Freeman RM, Swift SE, Cosson M, Davila GW, Deprest J, et al. An International Urogynecological Association (IUGA)/ International Continence Society (ICS) joint terminology and classification of the complications related directly to the insertion of prostheses (meshes, implants, tapes) and grafts in female pelvic floor surgery. *Neurourol Urodyn* 30:2-12, 2011; A Feola, M Endo, I Urbankova, J Vlacil, T Deprest, S Bettin, B Klosterhalfen, J Deprest. Host reaction to vaginally inserted collagen containing polypropylene implants in sheep. *Am J Obstet Gynecol* 212:474.e1-8, 2015.

¹¹³ ETH.MESH. 05588123

¹¹⁴ ETH.MESH. 07226481

¹¹⁵ Id

reactive species, the impact of which has not been clinically assessed."¹¹⁶

In summary, Ethicon scientists reported evidence of chronic inflammation, oxidation, and degradation (micro-cracking) of Prolene in preclinical studies and in human explants. These observations are consistent with the known susceptibility of polypropylene to oxidation outside the body, the known effects of the foreign body reaction on implanted biomaterials, and published studies on explanted PP mesh.¹¹⁷ Despite the fact that Ethicon scientists recommended additional testing to confirm or exclude the oxidation mechanism, I have found no evidence that these tests (which were available to Ethicon during development of the SUI and POP devices) were performed. Consequently, the risks inherent to Prolene oxidation and degradation are detrimental to all of those who have been implanted with the SUI and POP devices.

8) Using autologous fascia lata, allograft, sutures (including polypropylene sutures), or polyvinylidene fluoride (PVDF) mesh, does not present with the same chronic complications associated with the material properties of Ethicon's PP mesh. All of these alternative materials, including using a less dense version of its PP mesh, were available when Ethicon's SUI and POP meshes were first commercialized.

Implantable sutures, including PP sutures, have been used in procedures such as the Burch retropubic urethropexy, autologous and allograft biologic slings, and needle suspension procedures to treat SUI.¹¹⁸ As described above, the foreign body reaction is less persistent for sutures than for polypropylene mesh. In an early study investigating the effects of the foreign body reaction on Prolene sutures implanted in dogs, sutures were surrounded by fibroblasts, collagen, and a few macrophages at 1 – 3 months.¹¹⁹ From 3 months to 2 years, Prolene sutures were encapsulated in collagen with minimal adherent inflammatory cells.¹²⁰ In a later study characterizing the foreign body reaction associated with PP sutures and mesh in a rat abdominal wall model, PP mesh samples showed more adherent inflammatory cells than PP sutures.¹²¹ Recent studies investigating PP mesh explanted from human patients¹²² have reported adherent inflammatory cells near the surface of the PP

¹¹⁶ Id

¹¹⁷ VV Iakovlev*, SA Guelcher, R Bendavid. In vivo degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Appl Biomater Res: Part B Appl Biomater* 105(2):237-248, 2017.

¹¹⁸ ETH.MESH.00141933; AP Cameron, AM Haraway. The treatment of female stress urinary incontinence: an evidenced-based review. *Open Access Journal of Urology* 3:109-120, 2011; EC Trabuco, CJ Klingele, RE Blandon, JA Occhino, AL Weaver, ME McGree, MA Lemens, JB Gebhart. Burch Retropubic Urethropexy Compared With Midurethral Sling With Concurrent Sacrocolpopexy: A Randomized Controlled Trial. *Obstet Gynecol.* 2016 Oct;128(4):828-35

¹¹⁹ C Mary, Y Marois, MW King, G Laroche, Y Douville, L Martin, R Guidoin. Comparison of the In Vivo Behaviour of Polyvinylidene Fluoride and Polypropylene Sutures Used in Vascular Surgery. *ASAIO Journal* 44:199-206, 1998. ML Konstantinovic, E Pille, M Malinowska, E Verbeken, D De Ridder, J Deprest. Tensile strength and host response towards different polypropylene implant materials used for augmentation of fascial repair in a rat model. *Int Urogynecol J* 18:619-26, 2007.

¹²⁰ Id.

¹²¹ ML Konstantinovic, E Pille, M Malinowska, E Verbeken, D De Ridder, J Deprest. Tensile strength and host response towards different PP implant materials used for augmentation of fascial repair in a rat model. Deprest et al. *Int Urogynecol J* 18:619-26, 2007.

¹²² VV Iakovlev, SA Guelcher, R Bendavid. In vivo degradation of polypropylene: microscopic analysis of meshes explanted from 130 patients. *J Appl Biomater Res: Part B Appl Biomater*, 2015 Aug 28 doi: 10.1002/jbm.b.33502; A Clavé, H Yahi. J-C Hammou, S Montanari, P Gounon, H

fibers at periods of time from 3 months to multiple years. These studies show that the foreign body reaction in response to mesh implantation continues until the mesh is explanted and is dose-dependent (*i.e.*, more PP mesh both in density and amount promotes a more persistent foreign body reaction). Thus, since the foreign body reaction associated with implantable PP sutures is less persistent compared to PP mesh, the use of sutures is preferred from a biomaterials perspective. Furthermore, there is the additional benefit that the suture procedures do not present the risk of mesh-related complications.

Biologic grafts are derived from natural tissue that has been processed to remove cells and antigens that trigger an immune response while preserving the extracellular matrix that stimulates ingrowth of cells and tissue remodeling.¹²³ They are preferred from a biomaterials perspective because they promote a regenerative versus a scarring response. Biologic grafts can be classified into three general categories: (1) autologous fascia lata (autograft), (2) cadaveric fascia or dermal tissue (allograft), and (3) bovine or porcine tissue (xenograft).¹²⁴ In contrast to synthetic grafts, biologic grafts are designed to promote vascularization and tissue remodeling, not scarring.¹²⁵ Biologic grafts are resorbed and replaced by new tissue, thereby eliminating the types of complications associated with PP mesh. In contrast, the foreign body reaction associated with implantation of PP mesh persists for years and is not resolved until the mesh is removed, resulting in oxidation, embrittlement, and degradation. Thus, autografts and allografts eliminate the types of complications associated with the degradation of PP products in the pelvis.

Allografts are medical products that have been prepared from human cadaveric fascia¹²⁶ and human dermis.¹²⁷ Allografts include DuraDerm (Bard, decellularized human dermis), FasLata (Bard, cadaveric fascia lata), and Repliform (Boston Scientific, decellularized human cadaveric dermis). They are indicated for repair or replacement of damaged or inadequate integumental tissue, such as in the treatment of urinary incontinence, and for pelvic floor reinforcement or other conditions resulting from inadequate or damaged integumental tissue. Dermal allografts such as Repliform are processed under unique conditions to maintain the structure of the collagen and stimulate fibroblast remodeling of the extracellular matrix, resulting in cellular infiltration, vascularization, and new tissue ingrowth to achieve regenerative repair with reduced scarring and risk of exposure.¹²⁸ In a prospective series of 253 patients with SUI treated with a transvaginal sling using a Repliform cadaveric human dermal allograft and a bone anchor fixation kit, 234 of 253 patients were followed up at an average of 18 months.¹²⁹ 78% of the patients were cured or

Clavé. PP as a reinforcement in pelvic surgery is not inert: comparative analysis of 100 explants. *Int Urogynecol J* 21:261-270, 2010; A Imel, T Malmgren, M Dadmun, S. Gido, J Mays. In vivo oxidative degradation of polypropylene pelvic mesh. *Biomaterials* 73:131-141, 2015; AL Nolfi, BN Brown, R Liang, SL Palcsey, MJ Bonidie, SD Abramowitch, PA Moalli. Host response to synthetic mesh in women with mesh complications. *Am J Obstet Gynecol* 215:206.e1-8, 2016.

¹²³ ETH.MESH.00141933

¹²⁴ ETH.MESH.04941016

¹²⁵ ETH.MESH.04941016

¹²⁶ SL Brown, FE Govier. Cadaveric versus autologous fascia lata for the pubovaginal sling: surgical outcome and patient satisfaction. *J Urology* 164, 1633—1637, 2000.

¹²⁷ S Crivellaro, JJ Smith, E. Kocjancic, JF Bresette. Transvaginal sling using acellular human dermal allograft: safety and efficacy in 253 patients. *J Urology* 172, 1374—1378, 2004.

¹²⁸ ETH.MESH.00141933

¹²⁹ S Crivellaro, JJ Smith, E. Kocjancic, JF Bresette. Transvaginal sling using acellular human dermal allograft: safety and efficacy in 253 patients. *J Urology* 172, 1374—1378, 2004

improved according to patient questionnaires. Most significantly, there were no cases of vaginal or urethral erosion.¹³⁰

Polyvinylidene fluoride (PVDF) is a synthetic polymer manufactured by polymerization of vinylidene difluoride. As shown in Figure 10, PVDF is one of the least readily oxidized polymers, while PP is one of the most.¹³¹ PVDF sutures are used extensively in orthopaedic and cardiovascular surgery.¹³² In 1988, Mary et al. compared PROLENE to PVDF sutures in a canine thoracoabdominal bypass model for 10 periods of implantation ranging from 4 hours to 2 years.¹³³ PROLENE sutures explanted after 1 or 2 years implantation time showed evidence of surface cracking by SEM. In contrast, PVDF sutures explanted after 1 or 2 years did not show evidence of surface cracking when analyzed by SEM. These findings led the authors to conclude that PVDF “may be more biostable than polypropylene in the long term.” In another long-term study, PVDF sutures preserved 92.5% of their initial strength after 9 years of implantation compared to 54.4% for PP sutures due to oxidation of the PP.¹³⁴

In 1985, Ethicon implanted 24 beagles with PROLENE, PVDF, Ethilon, and Novafil sutures implanted subcutaneously in a 10-year study. Sutures were explanted at 5 or 7 years (the study was ended prematurely due to the unexpected death of one of the dogs at 6 years and 10.5 months). At 5 years, surface cracking was observed by SEM for 2 of the 5 PROLENE sutures, while surface cracking was not observed for any of the PVDF sutures. At 7 years, PROLENE sutures explanted from 3 of the 7 sites showed surface cracking by SEM, while only 1 of the 6 PVDF sutures showed evidence of surface cracking. The authors noted that only PDVF and Novafil sutures showed only marginal surface changes. The authors concluded that “degradation in PROLENE is still increasing and PVDF, even though a few cracks were found, is still by far the most surface resistant in-house made suture in terms of cracking.”¹³⁵ These findings are consistent with those from the Mary et al. study¹³⁶ and the resistance of PVDF to oxidative degradation.¹³⁷

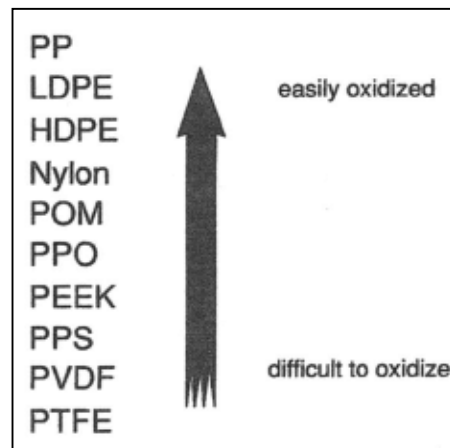


Figure 10. Tendency of various polymers to undergo oxidation. Reproduced from Compositional and Failure Analysis of Polymers, 2000, p.398, 426.

¹³⁰ SL Brown, FE Govier. Cadaveric versus autologous fascia lata for the pubovaginal sling: surgical outcome and patient satisfaction. *J Urology* 164, 1633—1637, 2000. BJ Flynn, WT Yap. Pubovaginal sling using allograft fascia lata versus autograft fascia for all types of stress urinary incontinence: 2-year minimum followup. *J Urology* 167, 608—612, 2002.

¹³¹ Compositional and Failure Analysis of Polymers, 2000, p. 398, 426.

¹³² K Junge, M Binnebösel, KT von Trotha, R Rosch, U Klinge, UP Neumann, PL Jansen. Mesh biocompatibility: effects of cellular inflammation and tissue remodeling. *Langenbecks Arch Surg* 2011, DOI 10.1007/s00423-011-0780-0.

¹³³ C Mary, Y Marois, MW King, G Laroche, Y Douville, L Martin, R Guidoin. Comparison of the In Vivo Behaviour of Polyvinylidene Fluoride and polypropylene Sutures Used in Vascular Surgery. *ASAIO Journal* 44:199-206, 1998.

¹³⁴ G Laroche, Y Marois, E Schwarz, et al. Polyvinylidene fluoride monofilament sutures: can they be used safely for long-term anastomoses in the thoracic aorta? *Artif Organs* 19 (11):1190–9, 1995.

¹³⁵ ETH.MESH.05453719; ETH.MESH.11336474

¹³⁶ C Mary, Y Marois, MW King, G Laroche, Y Douville, L Martin, R Guidoin. Comparison of

In an Ethicon-funded study, two PVDF hernia meshes were compared to PROLENE to assess differences in function tissue response. Mesh was implanted in a rat abdominal wall inlay model for 3, 14, 21, 42 and 90 days.¹³⁸ PVDF meshes showed significantly decreased inflammatory and fibrous tissue reactions compared to PROLENE mesh. After day 3, the PVDF meshes showed a significantly lower volume fraction of inflammatory cells compared to PROLENE mesh. PROLENE mesh showed an increased volume fraction of granulocytes, macrophages, and fibroblasts compared to PVDF meshes. In contrast, PVDF meshes showed a higher volume fraction of foreign body giant cells, which are indicative of a primarily chronic response. The authors further noted that PVDF meshes showed similar cellular responses despite their differences in weight. The moderate foreign body reaction observed for the PVDF meshes showed fewer granulocytes, macrophages, and fibroblasts, and a greater number of foreign body giant cells. Based on these findings, the authors concluded that both PVDF meshes induced significantly lower inflammation and fibrosis compared to PP mesh, and that PVDF is a possible alternative material to PP.

Internal Ethicon documents reveal that Ethicon employees and consultants were aware of the improved biostability of PVDF compared to PP. In 2007, Dr. Kersin Spychaj, an Ethicon employee, wrote a memo on mesh shrinkage based on a literature review.¹³⁹ Dr. Spychaj noted that PP induces a rapid and acute inflammatory response, and concluded that the ideal mesh induces a “mild but not excessive FBR.” Also in a 2007 email, Dr. Dieter Engel, an Ethicon employee, stated that Ethicon will move to Pronova (a copolymer of PVDF and hexafluoropropylene) as the future material for mesh due to its reduced foreign body reaction compared to PROLENE.¹⁴⁰ In a 2011 interview on mesh erosion conducted by PA consulting group on behalf of Ethicon, Professor Klosterhalfen noted that PP meshes degrade over time, and that Dynamesh, a PVDF mesh manufactured by FEG Textiltechnik, is one of the most stable materials he has seen.¹⁴¹ Also in 2011, the PA Consulting Group issued a report on mesh exposure in the pelvic floor.¹⁴² They noted that investigation of the causes of mesh exposure is “further complicated by known factors, such as the propensity of polypropylene (PP) to suffer degradation.” They further noted that while PP has a long history of use, it is subject to degradation, which has been observed in animal studies. The authors proposed PVDF as an alternative polymer for manufacture of pelvic mesh.

FACTS OR DATA CONSIDERED IN FORMING OPINIONS

The opinions and the bases for those opinions are set forth above. In addition to my knowledge, skill training and experience as an engineer, the following depositions of Ethicon employees and the exhibits thereto were supplied to me: Cliff Volpe, Piet Hinoul, David Robinson, Sunny Rah, Aaron Kirkemo, Sean O'Bryan, Scott Ciarrocca, Vincenza Zaddem, Elizabeth Vailhe, Christophe Vailhe, Joerg Holste, Boris Batke, Daniel Burkley, Thomas Barbolt, Brigitte Hellhammer, Juergen Trzewik, Martin Weisberg, Axel Arnaud, Dan Smith, Prof Thomas Muehl, Dr. Bernd Klosterhalfen, Kevin Ong, Whenxin Zheng,

the In Vivo Behaviour of Polyvinylidene Fluoride and polypropylene Sutures Used in Vascular Surgery. *ASAIO Journal* 44:199-206, 1998.

¹³⁷ Compositional and Failure Analysis of Polymers, 2000, p. 398, 426.

¹³⁸ U Klinge, B Klosterhalfen, AP Ottingerc, K Junge, V Schumpelick. PVDF as a new polymer for the construction of surgical meshes. *Biomaterials* 23 (2002) 3487–3493.

¹³⁹ ETH.MESH.01218361.

¹⁴⁰ ETH.MESH .05447475.

¹⁴¹ ETH.MESH.07192412.

¹⁴² ETH.MESH.07192412.

Daniel Sexton, and Jeffrey Brent.

I have also considered the following material identified in Exhibit B.

In addition, the following reports were supplied to me: Dr. Howard Jordi, Dr. Russell Dunn, Prof Thomas Muehl, Prof. Bernd Klosterhalfen, Thomas Barbolt, Dr. Wenxin Zheng, and B. Todd Heniford, M.D. The findings of these experts are consistent with my opinions.

COMPENSATION

A fee sheet has been attached as Exhibit C.

**LISTING OF CASES IN WHICH TESTIMONY HAS BEEN GIVEN IN
THE LAST FOUR YEARS**

- IN RE PELVIC MESH AMS LITIGATION, SERRANO ET AL – SEPTEMBER 2013
- IN RE PELVIC MESH ETHICON LITIGATION, HUSKEY ET AL. - MARCH 2014
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, ALBRIGHT ET AL – JULY 2014
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, CARDENAS ET AL – AUGUST 2014
- IN RE PELVIC MESH ETHICON LITIGATION, HUSKEY ET AL – AUGUST 2014
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, BARBA ET AL - FEBRUARY 2014
- IN RE PELVIC MESH BARD LITIGATION, CORRIVEAU ET AL – NOVEMBER 2014
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, FRANKUM ET AL – DECEMBER 2014
- IN RE PELVIC MESH ETHICON LITIGATION, PERRY - DECEMBER 2014
- IN RE PELVIC MESH ETHICON LITIGATION, PERRY – JANUARY 2015
- IN RE PELVIC MESH AMS LITIGATION, KILGORE ET AL - FEBRUARY 2015
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, BARBA ET AL - MAY 2015
- IN PELVIC MESH ETHICON LITIGATION, BRYANT ET AL – SEPTEMBER 2015
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, CARLSON ET AL – OCTOBER 2015
- IN RE PELVIC MESH ETHICON LITIGATION, WAVE 1 – MARCH 2016
- IN RE PELVIC MESH BOSTON SCIENTIFIC LITIGATION, VESTER ET AL – OCTOBER 2016
- IN PELVIC MESH BARD LITIGATION – APRIL 2017



Scott Guelcher, Ph.D.
Guelcher Consulting, LLC